

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

**THE EFFECTS OF DRYING METHODS AND STORAGE
CONDITIONS ON PEA SEED (*Pisum sativum* L.) QUALITY
AND THE RELATIONSHIP BETWEEN HIGH TEMPERATURE
DRYING AND MAIZE SEED (*Zea mays* L.) STRESS CRACKS.**

This thesis presented in fulfilment of the requirements for the degree of
Master of Applied Science (Agricultural Engineering) in the Institute of
Technology and Engineering, Massey University, New Zealand

NGUYEN XUAN THUY

1998

Dedicated to my parents and my lovely children

ABSTRACT

High temperature and high relative humidity adversely affect the quality of seeds, and are features of tropical climate. Seed drying and storage are being used increasingly in developing countries to improve seed storage and quality. This study was undertaken to evaluate a range of seed drying methods and storage conditions with the view to selecting an appropriate method(s) for use in tropical countries.

Pea (*Pisum sativum* L.) seeds at three initial seed moisture content (m.c.) of 23.8, 18.0 and 14.5% were dried to 10% seed m.c. before storage. The performances of four different drying methods: artificial dryer (Kiwi Mini) set at 30°C or 45°C, natural sun drying, and in-bin natural ventilation drying were evaluated. Natural sun drying, and in-bin natural ventilation drying were conducted from March to May, 1997, when mean temperature and relative humidity during sunny days were 17°C and 60% respectively. The dried seeds were stored under two conditions: open storage at 20.5°C and 55% relative humidity (r.h.), and closed storage at 25°C and 90% r.h. for 20, 40, and 60 days.

Time and energy consumed for drying by the different methods were determined to compare the drying efficiency when combined with quality of the seed. Deterioration of the seed due to storage conditions and drying methods used was determined by assessing their effects on seed germination, abnormal seedlings, dead seed, hollow heart percentages, and conductivity.

Seed samples dried by the Kiwi Mini dryer set at 45°C took 7 hours and those set at 30°C took 17 hours. It took 54 hours with natural in-bin ventilation drying, while sun drying took 37 hours. However, energy consumed when drying seeds at 30°C was 17 kWh, which was more than twice that at 45°C. Seed germination was not significantly different between drying methods, but averaged only 75% because of

sprouting damage of the crop prior to harvest. Germinations after open and closed storage for 20 days did not differ, although some differences appeared after 40 days of storage. However, open and closed storage for 60 days significantly reduced seed germination to 54 and 33% respectively.

Because seeds are heat-sensitive, drying air temperature and drying rate are particularly important to avoid internal seed breakage, cracking and splitting, fungal growth, and loss of germination and vigour. Selected studies have shown that seed can be dried at high temperature for a short time, followed by tempering to re-distribute moisture and temperature inside the seed, thus reducing the percentage of cracking.

Thus, a second experiment was conducted with maize (*Zea mays* L.) to study the impact on seed viability of high temperature drying followed by tempering. Maize at 28.5% initial seed m.c. was dried at 60°C for short periods of 5, 10, 15, 20, or 25 minutes, followed by tempering for 45 minutes at either 30°C or 21°C. This cycle was repeated until maize seeds were dried to 13.0% m.c.. The percentage of cracked seeds, germination immediately after drying, and after an accelerated ageing test, did not differ between 30°C and 21°C tempering. Drying exposure times of upto 10 minutes per cycle at 60°C caused vertical cracks in up to 50% of seeds, but seed germination remained over 90% and seed vigour was also maintained. The percentage of seeds with stress cracks due to high temperature drying (5 - 25 minute cycles) at 60°C followed by tempering had polynomial relationships with seed germination and vigour. Seeds dried at the same temperature without tempering had their germination reduced from 99 to 20%.

ACKNOWLEDGEMENTS

I am deeply indebted to my chief supervisor Dr. M.A. Choudhary, Senior Lecturer, Institute of Technology and Engineering, and co-supervisor Assoc. Professor J.G. Hampton, Institute of Natural Resources for their teaching, supervision, advice and encouragement during my study at Massey University.

I would like to thank Professor M.J. Hill for his friendly advice, Messrs. Gerard Harrigan, Russell Watson, Robert Southward and Craig McGill for their help during my experiments. My appreciation and sincere thanks are to all staff of the Agricultural Engineering Department (now part of the Institute of Technology and Engineering), and the Seed Technology Centre (now part of the Institute of Natural Resources) for their friendly and helpful cooperation.

Thank is also due to Dr. Steve Green, Horticultural Research Institute for supplying climate data.

I would like to extend my appreciation and thanks to the Government of New Zealand for financial assistance, and to the Vietnam Institute of Agricultural Engineering for allowing me to study at Massey University, New Zealand.

Finally, my thanks are to my father, mother-in-law, and wife for their encouragement.

TABLE OF CONTENTS

Contents	Page
Abstract	i
Acknowledgements	iii
Table of Contents	iv
List of Tables	xi
List of Figures	xiv
List of Appendices	xviii
 Chapter I: INTRODUCTION	 1
 Chapter II: LITERATURE REVIEW	 3
2.1. Importance of grain and seed drying and storage	3
2.2. Status of grain drying and storage in Vietnam	5
2.3. Status of drying and storage in New Zealand	8
2.4. Grain quality	9
2.5. Grain properties	10
2.6. Theory of drying	11
2.7. Methods of drying	13
<i>2.7.1. Natural drying</i>	14
2.7.1.1. Natural Sun drying	14
2.7.1.2. Natural In-Bin Ventilation	14

2.7.2. Artificial drying	15
2.7.2.1 Classifying levels of drying temperature	15
a. Low temperature drying	15
b. Medium temperature drying	16
c. High temperature drying	17
2.7.2.2. Dryer design types	19
a. In-bin drying systems	19
Low temperature drying	19
Continuous counter-flow drying	20
Batch-in-bin dryers	21
b. Off-farm drying systems	22
Cross-flow dryers	22
Concurrent-flow dryers	23
Mixed-flow dryers	24
c. On-farm drying systems	25
2.7.3. Microwave drying	25
2.8. Effect of drying temperature	26
2.8.1. Quality of grain used for human consumption	28
2.8.2. Quality of grain used for animal feed	31
2.8.3. Oily seed quality	32
2.8.3. Quality of seed	32
2.9. High temperature drying followed by tempering	34
2.10. Storage	37

2.11. Research Objectives	39
Chapter III: MATERIALS AND METHODOLOGY	41
<u>Experiment 1: COMPARISON OF PEA SEED DRYING METHODS</u>	41
3.1. Field growing of seed grain	41
3.2. Seed preparation	42
3.3. Experimental treatments	43
3.3.1. Microwave drying	43
3.3.2. Natural sun drying	44
3.3.3. In-bin natural ventilation drying	45
3.3.4. Artificial drying	46
3.4. Parameters and measurement procedures	47
3.4.1. Seed moisture content	47
3.4.2. Seed germination	48
3.4.3. Conductivity of the seed	50
3.4.4. Hollow heart	52
3.4.5. Expected field emergence	52
3.4.6. Air velocity	52
3.4.7. Temperature	53
3.4.8. Weather data	54
3.4.9. Determination of energy consumption	54
3.4.9.1. Artificial drying	55
3.4.9.2. Natural sun drying	56

3.4.9.3. In-bin natural ventilation drying	57
3.5. Storage conditions	59
Experiment 2: EFFECT OF HIGH TEMPERATURE DRYING AND TEMPERING ON MAIZE SEED QUALITY	61
3.6. Introduction	61
3.7. Seed preparation	62
3.8. Experimental treatments	62
3.9. Parameters and measurement procedures	63
3.9.1. <i>Seed moisture content</i>	63
3.9.2. <i>Stress cracking</i>	63
3.9.3. <i>Seed germination</i>	64
3.9.4. <i>Accelerated ageing test</i>	65
3.9.5. <i>Conductivity of the seed</i>	66
3.10. Data analysis	66
Chapter IV: RESULTS AND DISCUSSION	67
Experiment 1: COMPARISON OF PEA SEED DRYING METHODS	67
RESULTS	67
4.1. Effect of drying methods	67
4.1.1. <i>Drying time</i>	67
4.1.2. <i>Energy Consumption</i>	67
4.1.3. <i>Seed germination</i>	69
4.1.4. <i>Abnormal seedling and dead seed percentages</i>	69

4.1.5. <i>Seed conductivity and hollow heart</i>	70
4.1.6. <i>Seed quality following storage</i>	71
a. <i>20 days</i>	71
b. <i>40 days</i>	72
c. <i>60 days</i>	72
4.2. <i>Effect of initial moisture content</i>	73
4.2.1. <i>Time and energy consumption</i>	73
4.2.2. <i>Seed quality immediately after drying</i>	74
4.2.3. <i>Seed quality after storage</i>	75
4.3. <i>Effect of storage time</i>	75
4.3.1 <i>Seed germination</i>	75
4.3.2. <i>Abnormal seedlings</i>	76
4.3.3. <i>Dead seeds</i>	77
4.3.4. <i>Seed conductivity</i>	77
4.3.5. <i>Hollow heart</i>	78
4.3.6. <i>Seed moisture content</i>	79
4.4. <i>Effect of storage conditions</i>	80
4.4.1. <i>Seed germination, abnormal seedling and dead seed percentage</i>	80
4.4.2. <i>Seed conductivity</i>	80
4.4.3. <i>Seed hollow heart</i>	81
4.4.4. <i>Seed moisture content</i>	81

DISCUSSION	82
1. Drying time and energy consumption	82
2. Seed quality	83
<i>a. Microwave drying</i>	84
<i>b. Seed germination</i>	84
<i>c. Seed conductivity and hollow heart</i>	87
3. Seed moisture content in storage	90
SUMMARY	92
 <u>Experiment 2:</u> EFFECT OF HIGH TEMPERATURE DRYING AND TEMPERING ON MAIZE SEED QUALITY	 93
RESULTS	93
4.5. Effect of exposure time to drying at 60°C followed by tempering at 21°C on seed quality	93
4.5.1. <i>Percentage of cracked seeds</i>	93
4.5.2. <i>Germination</i>	94
4.5.3. <i>Abnormal seedlings</i>	95
4.5.4. <i>Percentage of dead seeds</i>	95
4.5.5. <i>Conductivity</i>	96
4.6. Effect of exposure time to drying at 60°C followed by tempering at 30°C on seed quality	97
4.6.1. <i>Percentage of cracked seeds</i>	97
4.6.2. <i>Germination</i>	97
4.6.3. <i>Abnormal seedlings</i>	98

4.6.4. <i>Percentage of dead seeds</i>	98
4.6.5. <i>Conductivity</i>	99
4.7. Effect of tempering temperature on seed quality	100
4.7.1. <i>Percentage of cracked seeds</i>	100
4.7.2. <i>Germination</i>	101
4.7.3. <i>Conductivity</i>	101
 DISCUSSION	 102
1. Effect of exposure time to drying at 60°C followed by tempering on seed quality	102
a. <i>Percentage of cracked seeds</i>	102
b. <i>Germination</i>	103
c. <i>Conductivity</i>	105
2. Relationship between high temperature drying induced cracks and seed germination and vigour	105
 SUMMARY	 110
 Chapter V: CONCLUSIONS AND RECOMMENDATIONS	 111
 BIBLIOGRAPHY	 114
 APPENDICES	 123

LIST OF TABLES

Table	Title	Page
2.1	Maximum air temperature for drying various cereals and legumes	18
2.2	Critical temperatures (°C) used in drying wheat	28
2.3	Maximum safe drying temperatures	29
2.4	Drying temperature and starch yield in maize	30
2.5	Equilibrium moisture content (%) of grain seeds at 25°C and various relative humidities	39
3.1	Microwave drying test results	43
4.1	Abnormal seedling and dead seed percentages of pea seed after drying by different methods	70
4.2	Effects of drying methods on pea seed conductivity and hollow heart percentage	70
4.3	Effect of drying methods on seed quality after 20 days of storage	71
4.4	Effect of drying methods on seed quality after 40 days of storage	72
4.5	Effect of drying methods seed quality after 60 days of storage	73

4.6	Effects of initial seed moisture content on time and energy consumption required to dry seeds to 10% m.c.	74
4.7	Effects of initial moisture content on seed quality after drying	74
4.8	Effects of initial moisture content on seed quality in storage	75
4.9	Percentage of abnormal seedlings after different periods of storage	77
4.10	Percentage of dead seed after different periods of storage	77
4.11	Conductivity ($\mu\text{S}.\text{cm}^{-1}.\text{g}^{-1}$) after different periods of storage	78
4.12	Hollow heart percentage after different periods of storage	78
4.13	Conductivity, hollow heart percentage and seed moisture content under different storage conditions	81
4.14	Effect of exposure time to drying at 60°C followed by tempering at 21°C on percentage of maize seeds with cracks	93
4.15	Effect of exposure time to drying at 60°C followed by tempering at 21°C on abnormal seedling percentage	95
4.16	Effect of exposure time to drying at 60°C followed by tempering at 21°C on dead seed percentage	96
4.17	Effect of exposure time to drying at 60°C followed by	96

	tempering at 21°C on conductivity of the seed	
4.18	Effect of exposure time to drying at 60°C followed by tempering at 30°C on percentage of maize seeds with cracks	97
4.19	Effect of exposure time to drying at 60°C followed by tempering at 30°C on abnormal seedling percentage	99
4.20	Effect of exposure time to drying at 60°C followed by tempering at 30°C on dead seed percentage	99
4.21	Effect of exposure time to drying at 60°C followed by tempering at 30°C on conductivity of the seed	100
4.22	Effect of two tempering temperatures on percentage of maize seeds with cracks	100

LIST OF FIGURES

Figure	Title	Page
2.1	Safe conditions for storage	4
2.2	Selected types of mechanical dryers: 1) Flat-bed forced air, 2) Grain circulating with shutter, 3) Grain circulating with baffle, 4) Upright screen forced air, 5) Grain circulating with inverted troughs, 6) Grain circulating with multiple air duct	5
2.3	Schematic drawing of a manual grain dryer using a cooking stove as the heat source	6
2.4	Schematic drawing of a bed dryer with pneumatic-fed rice husk furnace	7
2.5	Psychrometric chart and heating-drying processes	12
2.6	Schematic diagram of (a) On-floor dryer, (b) In-bin dryer, and (c) Tunnel drying	16
2.7	Schematic diagram of (a) Tray dryer, (b) Radial flow dryer, and (c) Sack dryer	17
2.8	Schematic diagram of a high temperature continuous dryer	19
2.9	Schematic diagram of an in-bin continuous counter-flow system	20

2.10	Schematic diagram of on-floor in-bin batch drying system	21
2.11	a) Conventional cross-flow dryer with forced-air drying and cooling; b) Modified cross-flow dryer with reverse-airflow cooling	22
2.12	Two-stage concurrent-flow dryer with counter-flow cooler, tempering section	23
2.13	Schematic diagram of a mixed-flow grain dryer	24
3.1	Pea seed drying under natural sun condition	44
3.2	Grain drying bin with large funnel exposed to natural wind direction and a small opening in the rear wall	45
3.3	Kiwi Mini Dryer and equipment for drying	47
3.4	Germination rolls in the germination room	50
3.5	The Conductivity meter with the flasks of peas	51
3.6	Davis anemometer	53
3.7	Schematic diagram of drying air circulation: A- Ambient air, B- Heated air; and C- Discharged air	55
3.8	Schematic diagram of air circulation in Kiwi Mini dryer	56
3.9	Air reheating progress and energy calculation chart	58
3.10	Closed storage at 25°C temperature and 90% relative humidity	59

3.11	Open storage at ambient conditions of 20.5°C temperature and 55% relative humidity	60
3.12	A “Maggy lamp” model BG for checking seed stress cracks	63
3.13	Plastic chamber used for accelerated ageing test	65
4.1	Time consumption by selected drying methods	68
4.2	Energy consumption by selected drying methods	68
4.3	Seed germination percentage as affected by selected drying methods and conditions	69
4.4	Seed germination percentage as affected by periods of storage	76
4.5	Effects of storage period on seed moisture content	79
4.6	Effects of storage conditions on seed quality	80
4.7	Relationship between seed conductivity and germination during storage	89
4.8	Maize seed germination after drying and after the AA test in a 21°C tempering system with different exposure time cycles	94
4.9	Maize seed germination after drying and after the AA test in a 30°C tempering system with different exposure time cycles	98
4.10	Maize seed germination after drying and after the AA test at different tempering temperatures	101

4.11	Relationship between percentage of seeds with vertical stress cracks and seed germination immediately after drying	107
4.12	Relationship between percentage of seeds with total stress cracks and seed germination immediately after drying	107
4.13	Relationship between percentage of seeds with vertical stress cracks and seed germination after the AA test	108
4.14	Relationship between percentage of seeds with total stress cracks and seed germination after the AA test	108

LIST OF APPENDICES

Appendix	Title	Page
1	Drying characteristics of selected drying methods	123
2	Statistical data analysis of time and energy consumption using a SAS package	124
3	Seed germination raw data	126
4	Statistical data analysis of seed germination using a SAS package	127
5	Abnormal seedlings raw data	131
6	Dead seed raw data	132
7	Seed conductivity raw data	134
8	Statistical data analysis of seed conductivity using a SAS package	135
9	Hollow heart raw data	139
10	Seed moisture content raw data	140
11	Statistical data analysis of seed moisture content using a SAS package	142
12	Expected field emergence (EFE)	145
13	Raw data of maize seed with stress cracks	147

14	Statistical data analysis of maize seed stress cracks using a SAS package	148
15	Maize seed germination raw data	154
16	Statistical data analysis of maize seed germination using a SAS package	156
17	Statistical data analysis of maize seed conductivity using a SAS package	160